Int. J. Aquat. Biol. (2017) 5(2): 95-107
ISSN: 2322-5270; P-ISSN: 2383-0956
Journal homepage: www.ij-aquaticbiology.com

Original Article

Assessment of suitability of macrobenthic mollusc diversity to monitor water quality and shallow sediment quality in a tropical rehabilitated and non-rehabilitated wetland system

W.M. Dimuthu Nilmini Wijeyaratne*,[1]Bellanthudawage Kushan Aravinda Bellanthudawa

Department of Zoology and Environmental Management, Faculty of Science, University of Kelaniya, Sri Lanka.

Abstract: Six sampling sites were selected to represent different land use types in the rehabilitated and non-rehabilitated areas of a recreational wetland in Sri Lanka to study the suitability of macrobenthic mollusc diversity to monitor spatial and temporal variation in physico-chemical parameters of water and shallow sediments. Individuals belonging to six families and eight species were recorded during the study. The significantly highest mean abundance (individuals) of *Bithynia tentaculata* and *Pila globosa* were recorded in sites from the rehabilitated area and there was no significant temporal variation of mollusc abundance during the study. The abundance and diversity of mollusc community showed significant spatial variations and this study identified that *B. tentaculata* and *P. globosa* can be used as possible bioindicators to detect changes in water and shallow sediment quality in tropical wetland ecosystems

Article history:
Received 12 January 2017
Accepted 9 April 2017
Available online 25 April 2017

Keywords:
Biomonitoring
Principal Component Analysis
Diversity indices
Sri Lanka

Introduction

Molluscs are a very diverse and species rich phylum that is widely distributed in many types of ecosystems throughout the world. Different species of molluscs perform key functions in ecosystems maintaining the ecosystem balance and material cycling. Also, they serve as important components in the food webs of ecosystems as they have representatives in almost all the trophic levels. In addition, molluscs have been identified as excellent bioindicators due to their relatively immobility or sedentary adult stages, close contact with both bottom sediments and the water column, and ability to respond to many types of anthropogenic impacts, such as nutrient enrichment, oxygen availability, and changes in habitat structure (Bonada et al., 2006; Feio et al., 2007; Mereta et al., 2013). Adult stages of mollusc life cycle mostly occupy the bottom habitats in a wetland and therefore they are always in contact with shallow soft sediments and overlying water column. This allows them to respond quickly to any physical or chemical change in these environments. Therefore, the temporal and spatial variation of abundance, composition, and distribution of molluscs provide an index of the ecosystem (Barbour et al., 1999).

The wide distribution, ecological and ecotoxicological importance of the molluscs in ecosystem monitoring have attracted a lot of attention. Several biomonitoring studies have indicated that river bed compaction due to agricultural practices, eutrophiccation and different types of pollutants as causal factors for decline of freshwater molluscs species (Hartmut and Gerstmann, 2007). The adult and juvenile stages of freshwater mussel populations (*Villosa iris* and *Anodonta grandis*) were recorded to be declining due to activities such as dredging, agricultural runoff, industrial pollution and sedimentation (Jacobson et al., 1993). The accumulation of chromium (Cr) and cadmium (Cd) in soft parts of bivalve *Caelatura companyoi* and the gastropod snail *Cleopatra bulimoides* have showed the suitability of these species as suitable bioindicators of heavy metal pollution (Moloukhia and Sleem, 2011). In addition, juvenile stages of *Lampsilis cardium* has

* Corresponding author: W.M. Dimuthu Nilmini Wijeyaratne
E-mail address: dimuthu.wijeyaratne@kln.ac.lk
DOI: https://doi.org/10.22034/ijab.v5i2.288

been used for assessment of pore water ammonia in several regions of USA (Bartsch et al., 2003).

Heavy metal contamination of wetland ecosystems has also been assessed using bivalves such as mussels and oysters in temperate waters (Paez-Osuna et al., 1995; Riget et al., 1997). Also some recent ecological studies have used the presence-absence and abundance data of the gastropod *Patella caerulea* to assess heavy metal contamination in the Iskenderun Bay (Turkmen et al., 2005; Yuzereroglu et al., 2010). Gastropod and pelecypod species were identified as ideal bio-indicators for trophic stages classification of lentic and lotic environments (Clarke, 1979; Choubisa, 1992). The gastropod *Corbicula fluminea* has been used in Taiwan to study Arsenic (As) pollution via a biological early warning system in wetland health assessment. In Malaysia, *Melonides tuberculata* a freshwater mollusc has been utilized to assess the acute toxicity of Cu, Cd, Zn, Pb, Ni, Fe, Al, and Mn (Shuhaimi-Othman et al., 2012).

Although the molluscs are considered as an important bioindicator in most different ecosystems in the world, in Sri Lanka, mollusc species are less popular as bioindicator organisms compared to fish and other bioindicator species. There are very few published research on use of mollusks to trace ecotoxicity in the aquatic systems in Sri Lanka. In a study in Bolgoda canal and Waga stream, *Paludomus loricatus, P. zeylanicus, Planorbella trivolvis, Promacea bridgesi*, and *Cerithiidae* sp. have shown significant relationships with the variation of physicochemical parameters (Idroos and Manage, 2012). A comprehensive study done in the stretch in the Dutch canal, Sri Lanka, highlighted the importance of *Melanoides tuberculata, Thiara acanthica, Faunas ater,* and *Neritina perottetiana* as bioindicators (Gamlath and Wijeyaratne, 1997). Also another study conducted in the Negombo estuary to evaluate the diversity and distribution of microbenthic community with special reference to changing environmental variables indicated that the molluscs species such as *Cerithidea cingulate, Dentalium* sp.*, Hydrobiid* sp.*, Terebralia palustris, Faunus ater, Thiarid* sp., and several *Venerid* sp.*, Tellind* sp.*, Mytilid* sp.*,* are applicable as a good bioindicators in wetland health assessments (Dahanayaka and Wijeyaratne, 2010).

The present study was conducted in the Diyawwannawa wetland system which is a very popular recreational wetland located in the commercial capital of Sri Lanka. This wetland system is located in a very urbanized environment and part of the wetland is maintained under pristine conditions, while other part is a rehabilitated area surrounding the Parliament of Sri Lanka. The rehabilitated part of the wetland is dedicated for recreational purposes and effects of human disturbances in the rehabilitated area is higher compared to the natural wetland area. Due to the human interferences, there can be changes in the water and sediment quality of the rehabilitated area of the wetland system compared to the natural area and these changes may have significant effects on the associated sediment community structure. However, no previous research have been conducted to compare the changes of water and sediment quality and benthic community structure of these two areas of the Dyawannawa wetland system. Therefore, the present study was conducted to examine differences of water and shallow sediment quality parameters in the rehabilitated and natural areas of the Diyawannawa wetland system. In addition, as diversity of molluscs is closely related to the sediment and water quality of their associated habitats, hence, this study focused on effects of differences in water and sediment quality parameters on the diversity and abundance of macrobenthic molluscs in the Diyawannawa wetland system.

Materials and Methods

Study area: Diyawannawa wetland is one of the most popular urban wetlands in Colombo district Sri Lanka. This wetland is composed of rehabilitated and non-rehabilitated areas. In the rehabilitated areas of the wetland, some parts are dredged, banks are restored and the aquatic vegetation is removed using mechanical removal methods to improve the water retention capacity of the wetland. In the non–rehabilitated area of the wetland, the human

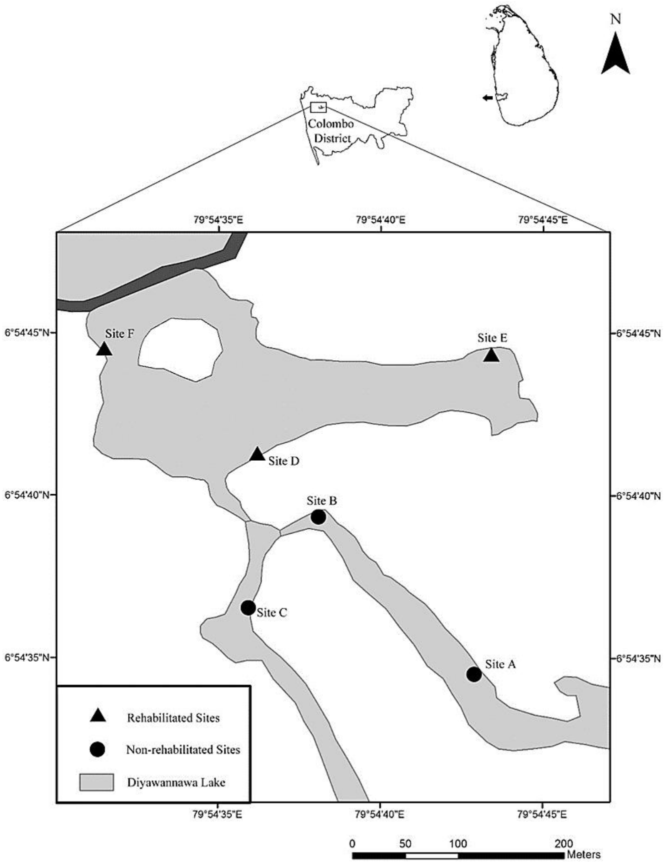

Figure 1. The study sites in the Diyawannawa wetland, Sri Lanka. Sites A, B and C are located in the non-rehabilitated area and sites D, E and F are in the rehabilitated area.

interventions on the wetland ecosystem are minimum and this area is rich in biodiversity and provides habitats for several threatened and endemic species in Sri Lanka.

The present study was carried out from April to December 2016. Six sampling sites were selected from the study area. The location of the sampling sites in the Diyawannawa wetland is shown in Figure 1. Site A (06°54'.585''N, 079°54'.722''E), site B (06°54'-.664''N, 079°54'.633''E) and site C (06°54'.609''N, 079°54'.604''E) were located in the non-rehabilitated area of the wetland. Site D (06°54'.68''N, 079° 54'.610''E), site E (06°54'.751''N, 079°54'.735''E) and site E (06°54'.741''N, 079°54'.525''E) were located in the rehabilitated area.

Sites A is characterized by thick vegetation cover in the wetland banks as well as presence of high density of floating aquatic macrophytes. Sites B and C are characterized by having a thick vegetation cover in the wetland banks and site D was characterized by absence of vegetation cover in the banks and presence of thick growth of aquatic macrophytes. Site E was receiving runoff from small scale poultry farms located within 100 meters of the wetland. Site F was located in a highly urbanized area.

Water and sediment quality parameters: From each site, water samples and shallow sediments samples (0-0.5 m depth) were collected. Sampling was carried out once in 6 weeks for a period of 7 months from April to December in 2016. At each sampling sites, water pH, temperature, conductivity, total dissolved solids (TDS) and salinity were measured in-situ using a calibrated digital multi parameter (YSI Environmental Model-556 MPS). Dissolved oxygen concentration (DO) was measured using DO meter (HQ 40b model-Hach). Visibility was recorded using a secchi disk. The biological oxygen demand 5 days after incubation (BOD_5), chemical oxygen demand (COD), nitrate concentration, chlorophyll α concentration and total and dissolved phosphorus concentrations were measured based on APHA (1992).

At each sampling site, sediment pH was measured in-situ using the calibrated digital multiparameter (YSI Environmental Model-556 MPS). Sediment organic matter content was measured in the laboratory using the loss on ignition method and the percentage sand, silt and clay content of the sediments were measured using the sedimentation jar. Water and sediment quality parameters were measured in triplicate within a 1 m^2 area and averaged for each sampling site.

Benthic mollusc diversity: Benthic mollusc sampling was carried out using the Peterson grab sampling method (Dahanayake and Wijeyaratne, 2006). The collected samples were preserved in 5% Rose bengal solution on site and were transported to the laboratory. In the laboratory at the University of Kelaniya, Sri Lanka, the samples were subjected to wet sieving through 4 mm, 2 mm and 1 mm mesh sieves to separate benthic molluscs. The organisms retained in each sieve were collected and preserved in 10% formalin and after a week they were transferred into 10% ethyl alcohol to prevent dehydration as described

Table 1. Spatial variation of water quality parameters at the sampling sites of the Diyawannawa wetland during the study period. The results are presented as mean±Standard Error of Mean. Different superscripts in each row indicate statistically significant differences (*P*<0.05).

Parameter	Non-rehabilitated area			Rehabilitated area		
	Site A	Site B	Site C	Site D	Site E	Site F
pH	5.98±0.3[b]	7.54±0.2[a]	7.63±0.3[a]	7.78±0.2[a]	7.38±0.2[a]	8.05±0.3[a]
Visibility (Cm)	42.7±4.0[a]	40.2±4.4[a]	37.7±1.5[a]	43.3±2.6[b]	30.8±1.7[bc]	23.76±1.2[c]
Temperature (^oC)	30.74±0.4[a]	31.34±0.3[a]	31.44±0.3[a]	31.54±0.4[a]	31.75±0.5[a]	32.14±0.3[a]
Conductivity (µs/cm)	345.5±10.5[a]	253.7±9.7[b]	271.6±14.6[b]	252.4±8.3[b]	248.69±4.8[b]	245.23±7.4[b]
Depth (cm)	85.5±3.2[bc]	118.6±9.5[a]	98.9±5.9[ab]	119.4±2.5[a]	85.7±6.2[bc]	62.7±6.8[c]
TDS ($mg.L^{-1}$)	166.25±5.0[a]	121.68±4.7[b]	129.98±7.1[b]	120.47±4.0[b]	109.90±5.3[b]	116.84±3.6[b]
DO ($mg.L^{-1}$)	2.82±0.09[a]	6.84±0.4[b]	7.68±0.4[b]	7.81±0.4[b]	10.61±0.2[c]	10.28±1.0[c]
Salinity ($^o/_{oo}$)	0.16±0.004[a]	0.12±0.004[a]	0.12±0.006[a]	0.12±0.004[a]	0.11±0.006[a]	0.12±0.003[a]
BOD_5 ($mg.L^{-1}$)	1.20±0.5[c]	2.13±0.5[c]	3.85±0.3[b]	3.79±0.3[b]	6.56±0.3[a]	5.13±0.3[ab]
Total phosphate ($mg.L^{-1}$)	0.02±0.004[a]	0.02±0.003[a]	0.02±0.004[a]	0.03±0.005[a]	0.03±0.006[a]	0.04±0.008[a]
Nitrate ($mg.L^{-1}$)	0.01±0.001[a]	0.04±0.001[b]	0.02±0.002[a]	0.02±0.003[a]	0.04±0.004[b]	0.04±0.002[b]
Chlorophyll-a (mg/dm^3)	2.05±0.2[a]	11.45±1.7[b]	2.40±0.6[a]	10.61±0.5[b]	12.13±2.6[b]	12.42±1.9[b]
COD ($mg.L^{-1}$)	173.1±36.4[a]	305.3±44.7[b]	285.5±46.9[b]	384.9±38.8[b]	387.5±38.2[b]	454.8±30.1[b]

by Dahanayaka and Wijeyaratne (2006). Molluscs were identified to family level using keys given by Fernando and Weerawardhena (2002). The number of individuals of each taxon and the number of families at each sampling site were counted.

Using the species abundance data, species richness, taxa richness (TR), species density, Simpson's diversity index (D), Shannon-Wiener diversity index (H'), Pielou's evenness index (J), Modified Hilsenhoff Biotic index and percent contribution of dominant family were calculated for each sampling site at each sampling occasion and data were averaged over time for six sampling sites.

Statistical analysis: After confirming the normality using Anderson darling test, the data were analyzed using one way ANOVA followed by Tukey's pairwise comparison to determine the significance of the spatial and temporal variation of selected water quality and sediment quality parameters in the rehabilitated and non-rehabilitated sites of the Diyawannawa wetland.

A Principal Component Analysis (PCA) was used to determine water and sediment quality parameters and diversity and biotic indices that describes the distribution of benthic mollusks in the Diyawannawa wetland. MINITAB 14 statistical software package was used in the statistical analysis.

Results

Spatial variation of water quality parameters in sampling sites is given in Table 1. Temporal variation of shallow bottom water quality parameters is given in Table 2. There was no spatial variation in temperature, salinity and total phosphorous ($P>0.05$). Site A of the non-rehabilitated area showed significantly higher water pH, conductivity and TDS. However, this site showed significantly lower COD, DO and BOD_5 ($P<0.05$). The site B of the non-rehabilitated area and all the sites in the rehabilitated area showed significantly higher chlorophyll α concentration throughout the study period ($P<0.05$). There was no significant temporal variation in temperature, DO and salinity ($P>0.05$). However, the other physico-chemical parameters showed significant temporal fluctuations throughout the study period (Table 2).

The spatial variation of shallow sediment quality parameters in each sampling site is given in Table 3. The temporal variation of shallow sediment quality parameters is given in Table 4. The pH, percentage total organic carbon (TOC) and the percentage silt content of the shallow sediments did not show significant spatial variations ($P>0.05$), but the percentage sand content at sites E and F of the rehabilitated area were significantly lower and

Table 2. Temporal variation of water quality parameters at the sampling sites of the Diyawannawa wetland during the study period. The results are presented as mean±Standard Error of Mean. Different superscripts in each row indicate statistically significant differences ($P<0.05$).

Parameter	April	May	June	September	October
pH	$7.48±0.2^{a}$	$6.13±0.2^{b}$	$6.37±0.18^{b}$	$8.73±0.12^{c}$	$8.24±0.14^{c}$
Visibility (cm)	$31.7±3.2^{a}$	$48.0±3.4^{b}$	$34.3±3.1^{a}$	$36.0±1.3^{a}$	$32.0±1.9^{a}$
Temperature (°C)	$33.82±0.16^{a}$	$30.78±0.19^{a}$	$29.91±0.18^{a}$	$30.59±0.11^{a}$	$32.37±0.24^{a}$
Conductivity (µs/cm)	$278.11±4.8^{ab}$	$221.28±8.6^{c}$	$254.3±12.7^{bc}$	$289.4±11.8^{ab}$	$304.50±9.8^{c}$
Depth (cm)	$116.2±5.8^{a}$	$114.4±6.5^{b}$	$79.9±5.9^{b}$	$81.6±6.1^{b}$	$83.5±6.7^{b}$
TDS ($mg.L^{-1}$)	$133.57±2.52^{a}$	$98.20±4.75^{b}$	$121.49±6.13^{a}$	$138.88±6.05^{a}$	$145.45±4.72^{a}$
Dissolved Oxygen ($mg.L^{-1}$)	$8.05±0.8^{a}$	$6.90±0.7^{a}$	$8.14±0.8^{a}$	$7.26±0.5^{a}$	$9.00±0.7^{a}$
Salinity (‰)	$0.13±0.003^{a}$	$0.09±0.005^{a}$	$0.12±0.006^{a}$	$0.13±0.006^{a}$	$0.14±0.004^{a}$
BOD_5 ($mg.L^{-1}$)	$2.29±0.4^{a}$	$3.57±0.5^{ab}$	$3.94±0.4^{ab}$	$3.72±0.5^{ab}$	$5.37±0.4^{b}$
total phosphate ($mg.L^{-1}$)	$0.009±0.0005^{a}$	$0.011±0.001^{a}$	$0.009±0.0009^{a}$	$0.055±0.004^{b}$	$0.044±0.004^{b}$
Nitrate ($mg.L^{-1}$)	$0.035±0.003^{a}$	$0.031±0.004^{ab}$	$0.027±0.003^{ab}$	$0.024±0.003^{ab}$	$0.021±0.002^{a}$
Chlorophyll-a (mg/dm^3)	$8.29±1.0^{a}$	$5.961±0.8^{a}$	$4.578±0.7^{a}$	$14.83±2.8^{b}$	$4.571±0.6^{a}$
COD ($mg.L^{-1}$)	$504.6±16.9^{a}$	$445.6±42.3^{a}$	$288±20.1^{b}$	$253.2±37.6^{b}$	$167.7±19.5^{c}$

Table 3. Spatial variation of shallow sediment quality parameters at the sampling sites of the Diyawannawa wetland during the study period. The results are presented as mean±Standard Error of Mean. Different superscripts in each row indicate statistically significant differences ($P<0.05$).

Parameter	Non-rehabilitated area			Rehabilitated area		
	Site A	Site B	Site C	Site D	Site E	Site F
Percentage sand content	$44.6±9.7^{a}$	$54.3±11.9^{a}$	$48.7±10.6^{a}$	$42.7± 9.4^{a}$	$7.3±1.6^{b}$	$5.5±1.2^{b}$
Percentage silt content	$9.9±2.1^{a}$	$3.9±1.2^{a}$	$8.1±1.7^{a}$	$13.6± 3.1^{a}$	$11.9±2.6^{a}$	$13.1±2.8^{a}$
Percentage clay content	$45.5±11.9^{a}$	$41.8±12.7^{a}$	$43.3±12.4^{a}$	$43.8± 12.3^{a}$	$80.76±4.20^{a}$	$81.50±4.04^{a}$
Percentage TOC	$12.42±0.01^{ab}$	$12.34±0.02^{b}$	$12.36±0.03^{b}$	$12.35± 0.02^{b}$	$12.48±0.03^{a}$	$12.48±0.03^{a}$
Conductivity (µs/cm)	$47.98±0.6^{c}$	$43.80±0.7^{c}$	$70.87±2.5^{b}$	$74.49± 2.4^{b}$	$77.05±1.5^{b}$	$91.44±1.2^{a}$
pH	$6.19±0.08^{a}$	$5.76±0.24^{a}$	$6.17±0.11^{a}$	$6.12± 0.12^{a}$	$6.23±0.13^{a}$	$6.31±0.10^{a}$

Table 4. Temporal variation of shallow sediment quality parameters at the sampling sites of the Diyawannawa wetland during the study period. The results are presented as mean±Standard Error of Mean. Different superscripts in each row indicate statistically significant differences ($P<0.05$).

Parameter	April	May	June	September	October
Percentage sand content	$55.0±7.6^{a}$	$57.2±8.2^{a}$	$56.8±8.2^{a}$	$3.41±0.01^{b}$	$3.59±0.02^{b}$
Percentage silt content	$18.4±1.3^{a}$	$16.2±1.5^{a}$	$15.9±1.5^{a}$	$6.32±0.01^{b}$	$5.86±0.02^{b}$
Sediment clay %	$26.74±7.25^{b}$	$26.49±7.15^{b}$	$27.24±7.14^{b}$	$90.3±0.01^{a}$	$90.6±0.02^{a}$
Shallow sediment TOC%	$12.35±0.02^{a}$	$12.43±0.03^{a}$	$12.455±0.03^{a}$	$12.42±0.03^{a}$	$12.37±0.03^{a}$
Shallow sediment conductivity (µs/cm)	$68.24±4.4^{a}$	$68.39±4.4^{a}$	$68.22±4.2^{a}$	$68.01±4.04^{a}$	$65.17±4.5^{a}$
Shallow sediment pH	$6.13±0.23^{bc}$	$5.75±0.02^{c}$	$5.83±0.05^{c}$	$6.32±0.06^{ab}$	$6.60±0.05^{a}$

percentage clay content of these sites were significantly higher compared to the other sites (Table 3). The sites A and B of the non-rehabilitated area showed significantly lower sediment conductivity compared to other sites ($P<0.05$). There was no significant temporal variation of the percentage TOC, conductivity and pH of the shallow sediments of the study sites ($P>0.05$). However, the percentage sand and silt contents showed significant decrease and percentage clay content of the sediments showed a significant increase during September and October compared to other months ($P<0.05$).

The spatial variation of mean abundance of macrobenthic mollusk species in each sampling site is given in Table 5. The temporal variation of mean abundance of macrobenthic mollusc species during the study period is given in Table 6. In the present study, a total of 8 freshwater macrobenthic molluscs,

Table 5. Spatial variation of the mean abundance of freshwater macrobenthic molluscs species in each sampling sites of the Diyawannawa wetland during the study period. Different superscripts in each row indicate statistically significant differences (P<0.05).

Species Name	Non-rehabilitated Area			Rehabilitated Area		
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Bithynia tentaculata	3^{d}	3^{d}	8^{cd}	15^{bc}	17^{b}	35^{a}
Melanoides turbeculata	0^{b}	0^{b}	1^{b}	4^{a}	1^{b}	5^{a}
Melanoides turriculus	1^{b}	2^{ab}	4^{ab}	5^{a}	2^{ab}	3^{ab}
Thiara scabra	0^{b}	1^{b}	2^{b}	10^{a}	1^{b}	3^{ab}
Lamellidens marginalis	0^{c}	1^{c}	1^{c}	2^{b}	0^{c}	3^{a}
Pila globosa	0^{b}	0^{b}	0^{b}	0^{b}	1^{b}	2^{a}
Gyraulus saigonensis	1^{b}	1^{b}	1^{b}	1^{b}	3^{a}	2^{ab}
Lymnaea stagnalis	1^{b}	0^{b}	0^{b}	1^{b}	3^{a}	1^{b}

Table 6. Temporal variation of the mean abundance of freshwater macrobenthic molluscs species in each sampling sites in the Diyawannawa wetland during the study period. Different superscripts in each row indicate statistically significant differences (P<0.05).

Species Name	April	May	June	September	October
Bithynia tentaculata	8^{a}	12^{a}	18^{a}	15^{a}	15^{a}
Melanoides turbeculata	3^{a}	2^{a}	3^{a}	2^{a}	1^{a}
Melanoides turriculus	4^{a}	3^{a}	3^{a}	3^{a}	2^{a}
Thiara scabra	7^{a}	2^{a}	2^{a}	2^{a}	1^{a}
Lamellidens marginalis	1^{a}	1^{a}	1^{a}	1^{a}	1^{a}
Pila globosa	1^{a}	1^{a}	1^{a}	1^{a}	1^{a}
Gyraulus saigonensis	2^{a}	1^{a}	1^{a}	2^{a}	2^{a}
Lymnaea stagnalis	1^{a}	1^{a}	1^{a}	1^{a}	1^{a}

Table 7. Spatial variation of diversity and biotic indices of macrobenthic molluscs in the Diyawannawa wetland during the study period.

Site	Simpson's Diversity Index (D)	Shannon-Wiener Diversity Index (H')	Modified Biotic Index	Pielou's Evenness Index
A	0.613	1.1376	7.371	1.890
B	0.635	1.2033	7.160	1.721
C	0.660	1.3116	7.093	1.686
D	0.708	1.4177	6.873	1.678
E	0.506	1.1167	7.619	1.321
F	0.472	1.0978	7.548	1.216

Table 8. The percentage dominance of dominant macrobenthic mollusc family in each study site during the study period.

Site.	Dominant family	% Dominance
A	Bithyniidae	55.71
B	Bithyniidae	50.62
C	Bithyniidae	50.93
D	Thiaridae	53.50
E	Bithyniidae	68.66
F	Bithyniidae	71.56

species belonging to 6 families were recorded. The mean abundance of *Bithynia tentaculata* was significantly higher in site F in the rehabilitated area (P<0.05, Table 5). Only *B. tentaculata* and *Melanoides turbeculata* were recorded from site A of the non-rehabilitated area and the recorded numbers of these two species in this site were significantly lower compared to other study sites (Table 5). *Pila globosa* was recorded only at sites E and F of the rehabilitated area (Table 5). There was no significant temporal variation of the mean abundance of freshwater macrobenthic molluscs during the study period (Table 6).

The Shannon wiener diversity index, Simpsons index, modified biotic index and Pielou's evenness index for each sampling site are given in Table 7. The lowest values for Simpsons diversity index, Shannon wiener diversity index and Pielou's evenness index were recorded from site F in the rehabilitated area (Table 7). The highest values for Simpsons diversity index, Shannon wiener diversity index and modified biotic index were recorded from the Site D in the

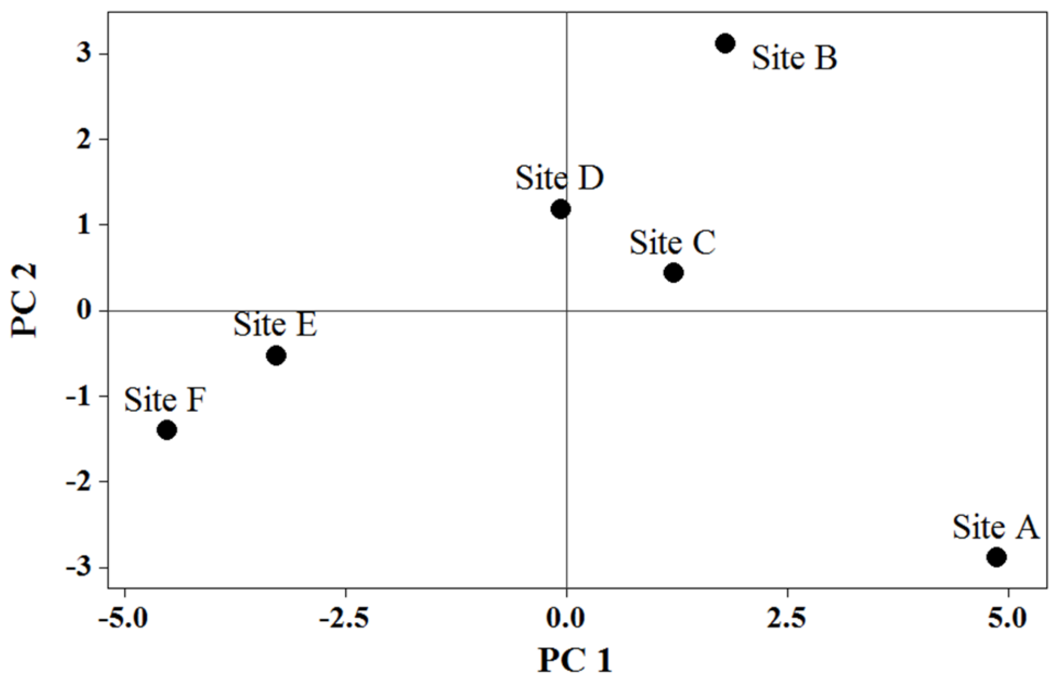

Figure 2. Ordination of the study sites based on PC1 and PC2 scores of PCA of the physico-chemical parameters of over lying water and sediments of the study sites in the Diyawannawa wetland (Sites A, B and C=non-rehabilitated area and sites D, E and F=rehabilitated area).

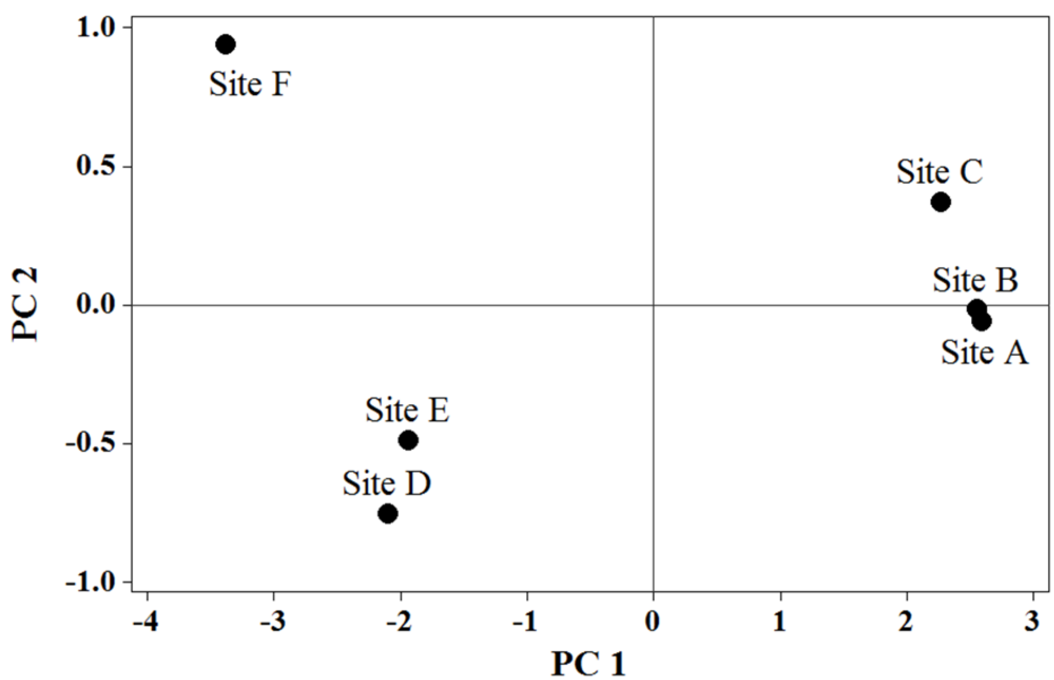

Figure 3. Ordination of the study sites based on PC1 and PC2 scores of PCA of the abundance of macrobenthic molluscs of the study sites in the Diyawannawa wetland. (Sites A, B and C=non-rehabilitated area and sites D, E and F=rehabilitated area).

rehabilitated area (Table 7). The diversity and biotic index values of the sites in the non-rehabilitated area showed similar values to each other (Table 7). The percentage dominance of dominant macrobenthic mollusc family in each study site during the study period is given in Table 8. All the study sites except Site D were dominated by the members of the family Bithyniidae and Site D was dominated by the family Thiaridae (Table 8).

PCA showed the categorization six sampling sites

Table 9. Summary of the PCA of physico-chemical parameters of water and shallow sediments of the study sites at the Diyawannawa wetland. Cumulative % variation of only the PC1 and PC2 are shown. A high cumulative percentage as high as 85.8% of the total variation among physico-chemical parameters are explained by PC1 and PC2 axis.

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	11.93	62.8	62.8
2	4.38	23.1	85.8

Eigenvectors (Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4	PC5
Water pH	-0.214	0.263	-0.204	0.145	-0.388
Temperature	-0.281	0.068	0.055	0.069	-0.252
EC	0.229	-0.290	-0.057	-0.026	0.021
TDS	0.240	-0.258	-0.018	-0.044	-0.187
DO	-0.277	0.104	0.026	0.186	0.144
BOD5	-0.264	-0.023	0.080	0.241	0.470
COD	-0.274	0.100	0.123	-0.197	-0.143
Nitrate	-0.213	0.184	-0.459	-0.046	-0.029
Chlorophyll a	-0.216	0.189	-0.180	-0.575	0.075
Total Phosphorus	-0.255	-0.117	0.116	-0.384	-0.289
Visibility	0.249	0.137	0.253	-0.225	0.303
Depth	0.135	0.380	0.225	-0.187	0.322
%TOC	-0.177	-0.337	-0.274	-0.046	0.191
Sediment pH	-0.128	-0.386	-0.290	-0.192	-0.058
%sand	0.249	0.218	0.141	0.088	-0.177
% Silt	-0.157	-0.257	0.453	-0.373	0.179
%clay	-0.248	0.194	-0.241	-0.028	0.160
Sediment conductivity	-0.251	-0.115	0.334	0.147	-0.134

Principal Component Scores

Sample	SCORE1	SCORE2	SCORE3	SCORE4	SCORE5
Site A(Non Rehabilitated Site)	4.871	-2.879	-0.373	-0.363	0.033
Site B(Non Rehabilitated Site)	1.797	3.130	-1.451	-0.261	-0.250
Site C (Non Rehabilitated Site)	1.207	0.448	0.839	1.573	-0.170
Site D (Rehabilitated site)	-0.071	1.198	1.957	-0.915	0.169
Site E (Rehabilitated site)	-3.286	-0.513	-0.683	0.156	1.208
Site F (Rehabilitated site)	-4.519	-1.384	-0.289	-0.181	-0.990

according to the water and sediment quality parameters. Two principal components displaying a cumulative variance of 85.8% were obtained after applying PCA on water and sediment quality parameters. PCA score plot for variation of water quality and sediment quality parameters among the study sites in the Diyawannawa wetland is given in Figure 2. The eigenvalues of the first two principal components, eigenvectors of the water and sediment quality variables and the principal component scores for the study sites are given in Table 9. According to the results of the PCA on water quality and sediment quality parameters, the sites C and B of the non-rehabilitated area and site D of the rehabilitated area grouped together. Sites E and F of the rehabilitated area were grouped together and site A of the non-rehabilitated area was separated from the other groups (Fig. 2).

Two principal components displaying a cumulative variance of 99.3% were obtained after applying PCA on total abundance of macrobenthic molluscs. PCA score plot for variation of total abundance of macrobenthic molluscs among the study sites in the Diyawannawa wetland is given in Figure 3. The eigenvalues of the first two principal components, eigenvectors of the total abundance of macrobenthic molluscs and the principal component scores for the study sites are given in Table 10. The results of the PCA on total abundance of macrobenthic molluscs also categorized six sampling sites into three groups. The Site F of the rehabilitated area was separated from other study sites. The three sampling sites of the non-rehabilitated area were grouped together and sites E and F of the rehabilitated area formed a separate group

Table 10. Summary of the PCA of total abundance of macrobenthic molluscs of the study sites at the Diyawannawa wetland. Cumulative % variation of only the PC1 and PC2 are shown. A high cumulative percentage as high as 99.3% of the total variation among physico-chemical parameters are explained by PC1 and PC2 axis.

Eigenvalues

PC	Eigenvalues	%Variation	Cum.%Variation
1	7.58	94.7	94.7
2	0.36	4.6	99.3

Eigenvectors (Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4	PC5
Bithynia tentaculata	-0.326	0.731	-0.037	-0.153	0.531
Melanoides turbeculata	-0.360	-0.199	0.176	0.282	0.288
Melanoides turriculus	-0.351	0.372	0.545	0.138	-0.650
Thiara scabra	-0.362	0.002	-0.316	-0.666	-0.209
Lamellidens marginalis	-0.361	-0.096	-0.374	0.267	-0.116
Pila globosa	-0.357	-0.298	-0.185	-0.209	-0.178
Gyraulus saigonensis	-0.362	-0.016	-0.320	0.526	0.030
Lymnaea stagnalis	-0.348	-0.435	0.543	-0.206	-0.350

Principal Component Scores

Sample	SCORE1	SCORE2	SCORE3	SCORE4	SCORE5
Site A(Non Rehabilitated Site)	2.590	-0.059	-0.051	0.040	0.039
Site B(Non Rehabilitated Site)	2.550	-0.016	0.012	0.056	-0.036
Site C (Non Rehabilitated Site)	2.269	0.373	0.065	-0.095	-0.003
Site D (Rehabilitated Site)	-2.098	-0.751	0.327	-0.005	0.002
Site E (Rehabilitated Site)	-1.935	-0.486	-0.387	-0.022	-0.005
Site F (Rehabilitated Site)	-3.375	-0.939	0.033	0.026	0.002

Table 11. Pearsons' Correlation coefficients between the abundance of fresh water molluscs species and shallow sediment quality parameters (* indicates significant correlations at 95% level of significance).

Species	Shallow sediment TOC	Shallow sediment pH	Shallow sediment conductivity	Sand %	Clay %	Silt %
Bithynia tentaculata	.327	.134	**.645***	**-.445***	**.365***	.133
Gyraulus saigonensis	.120	.282	.310	-0.341	.314	-.050
Lamellidens marginalis	.216*	.126	**.497***	-.267	.231	.023
Lymnaea stagnalis	**.665***	.154	.109	-.226	.189	.048
Melanoides turbeculata	0.195	0.063	**0.511***	.005	-.092	.392
Melanoides turriculus	-.062	.057	.148	.156	-.187	.221
Pila globosa	**.465***	.144	**.468***	-.332	.285	.042
Thiara scabra	-.028	.140	.166	.122	-.178	.310

Table 12. Criteria for evaluation of water quality using the family-level biotic index (Hilsenhoff, 1988).

Biotic index Value	Water quality	Degree of organic pollution
0.00-3.50	Excellent	No apparent organic pollution
3.51-4.50	Very good	Possible slight organic pollution
4.51-5.50	Good	Some organic pollution
5.51-6.50	Fair	Fairly significant organic pollution
6.51-7.50	Fairly poor	Significant organic pollution
7.51-8.50	Poor	Very significant organic pollution
8.50-10.0	Very poor	Severe organic pollution

on the PCA plot (Fig. 3).

The results of the Pearsons' correlation analysis on the total abundance of macrobenthic molluscs with selected water quality parameters is given in Table 11. The abundance of *B. tentaculata, Lamellidens marginalis, M. turbeculata* and *P. globosa* showed significant positive correlations with sediment conductivity. In addition, the abundance *B. tentaculata* showed significant positive correlations with percentage clay content and significant negative correlation with percentage sand content of the sediments. *Pila globosa* and *Lymnaea stagnalis* showed significant correlations with percentage total organic carbon content of the shallow sediments (Table 11).

Discussion

The distribution of moluscs in aquatic ecosystems are influenced by various ecological features of the sediments an overlying water column. Sediment characteristics are an important aspect of physical habitat in aquatic ecosystems. Sediments are the primary component of the substrate upon which macrobenthic molluscs move, rest, shelter, and feed. Therefore changes in the sediment characteristics can directly influence the mollusk community structure of the ecosystem. Molluscs are commonly used for biological monitoring of freshwater ecosystems in many parts of the world as they have limited mobility and are quite easy to collect using standard sampling techniques (Hellawell, 1986; Abel, 1989).

Begon et al. (2006) stated that in a healthy aquatic community, the evenness index ranges between 0.0 and 2.0, and the Shannon-Wiener's diversity index ranges between 1.5 and 3.5. During the present study in each site, Shonnon-Wiener Diversity index values were ranged in between 1.09- 1.42 and Pioulos' eveness indices values ranged between 1.2-1.9 indicating less variation of diversity and a healthy aquatic community in both non rehabilitated and rehabilitated areas of the Diyawanawa wetland system. Further, the significantly high value for Pielou's Evenness Index in sampling sites in non-rehabilitated area compared to the rehabilitated area reflect that there is an evenly distributed, less diverse freshwater macrobenthic molluscs community in rehabilitated area compared to the non-rehabilitated area.

However, among the species of molluscs recorded during the study, the number of individuals of *B. tentaculata* collected from the rehabilitated sites were significantly higher compared to that of the non-rehabilitated sites during the study period. The reason may be that the environmental parameters of the rehabilitated area may be significantly favorable for the survival and distribution of *B. tentaculata*. According to the Pearsons' correlation analysis the abundance of *B. tentaculata* showed significant positive correlations with sediment clay content and sediment conductivity. The PCA analysis based on water and shallow sediment quality parameters of the present study categorized sites E and F of the rehabilitated area together and these sites were characterized by high sediment clay content and high sediment conductivity. According to the PCA on abundance of macrobenthic molluscs, site F of the rehabilitated area was separated from the other study sites and *B. tentaculata* was the responsible species for the separation of site F. Therefore, the results of the present study agrees with studies conducted by Kołodziejczyk (1984) and Savage and Gazey (1987) indicating that there is a statistical significant relationship with bottom sediments clay percentage and organic matter with the abundance of *B. tentaculata* in lentic ecosystems. In the present study, sites D and E of the rehabilitated area were grouped together and was characterized by *P. globosa* and *L. stagnalis*. Further, *P. globosa* and *L. stagnalis* showed significant correlations with percentage total organic carbon content of the shallow sediments. This finding agrees with a study conducted in a tropical aquatic system in Bangladesh indicating tolerance of these species to organic enrichment and poor water quality (Badruzzaman et al., 2007).

In addition, according to the PCA on water and sediment quality parameters the sites A and B of the non-rehabilitated area and site D of the rehabilitated area were grouped together and were characterized by high visibility and high percentage sand content in the sediments. The sites A, B and D were located in close proximity to each other and this may have caused these sites to share common physical parameters. In the PCA of abundance of macrobenthic molluscs, the sites (A, B and C) in the non-rehabilitated area were grouped together and were characterized by abundance of *M. turriculus*. This shows that *M. turriculus* is a pollution sensitive species and therefore restricted to non-rehabilitated area. Also previous studies in tropical wetland systems has not identified the mussel species *M. turriculus* as a biomonitoring indicator that can be used in assessing the wetland health.

Plafkin et al. (1989) and Bode et al. (1991, 1996) stated that Modified Biotic Index is highly applicable and modified to incorporate non-arthropod species including molluscs to characterize the level of organic pollution input in the aquatic ecosystems. The input of organic pollutants and the water quality of the receiving aquatic system can be categorized based on the values of MBI and the categorization is given in Table 12 (Hilsenhoff, 1988). Significantly, high Modified Biotic Index (MBI) was recorded in sites E and F indicating a very significant level of input of organic pollutants and poor water quality in those sites. In addition, according to the variation of MBI sites, A, B and C in the non-rehabilitated area and site D of the rehabilitated area also indicated a significant organic pollution and fairly poor water quality.

In a study conducted to assess the water quality in the Diyawannawa wetland system for a five year period have recorded that the water nitrate concentration varied within a range 0.01-0.8 mg.L^{-1} (Dharmasoma and Piyadasa, 2010). In the present study, a similar variation of nitrate concentration from 0.02 to 0.09 mg.L^{-1} was recorded and the values recorded in the study are below the maximum standard ambient nitrate concentration (5 mg.L^{-1}) to maintain a healthy aquatic life established by the Central Environmental Authority of Sri Lanka (CEA, 2001).

Based on the results, there was no statistically significant spatial variation in the total phosphate concentration. But compared to the study sites in the non-rehabilitated area, the sites in the rehabilitated area showed higher total phosphate concentrations. The total phosphate concentration of the study sites ranged from 0.0009 to 0.066 mg.L^{-1}and it was also less than the maximum standard ambient nitrate concentration (0.4 mg.L^{-1}) to maintain a healthy aquatic life (CEA, 2001).

DO is identified to be negatively correlated with the organic pollution status of a wetland (Kazi et al., 2009). As recorded in a study conducted by Dharmasoma and Piyadasa (2014), the mean dissolved oxygen concentration of the selected sites of the Diyawannawa wetland ranged from 4.69-5.86 mg.L^{-1}. In the present study, mean dissolved oxygen concentration showed a wider range of variation with a range from 2.40 to 14.91 mg.L^{-1}. The dissolved oxygen concentration showed a significant spatial variation indicating a significantly lower dissolved oxygen concentration at site A of the non-rehabilitated area compared to other sites. During the field work, it was noted that this site had lot of floating macrophytes compared to other sites, thus disturbing the contact of aquatic and atmospheric interphase. This may have reduced the atmospheric input of oxygen of this site. The mean oxygen concentration recorded in site A of the non-rehabilitated area was less than the standard minimum ambient dissolved oxygen concentration (3 mg.L^{-1}) established by the CEA, but the other sites showed higher values than the ambient minimum standard.

In the present study, there is a significant increment in BOD_5 and COD in the rehabilitated area compared to those of non-rehabilitated area. COD is a measurement used to detect the input of domestic sewage, agricultural and industrial waste into aquatic systems and high BOD and COD can be recorded in aquatic systems where extensive domestic waste dumping is pracised (Kazi et al., 2009; Triest et al., 2001). In the present study, improper solid waste dumping and discharging of waste from nearby residents was observed in sites E and F of the rehabilitated area, which may have contributed to significantly high levels of BOD and COD. However, the BOD values recorded during the study were less than the maximum ambient BOD (4 mg.L^{-1}) and the COD values were higher than the maximum ambient COD (15 mg.L^{-1}) values established by the CEA of Sri Lanka.

The results of the present study showed a significant spatial and temporal variation of physicochemical parameters of water and shallow sediment quality in the rehabilitated and non-rehabilitated areas of the Diyawannawa wetland system affecting the abundance and diversity of macrobenthic molluscs. Therefore, it highlights the importance of continuous monitoring of water and sediment quality, and fresh water macrobenthic mollusc diversity as reflect the health of this wetland system. The results also showed that abundance of *B. tentaculata* and *P. globosa* can be used as a biomonitoring tool to assess sediment quality in relation to their positive interaction with sediment quality and their abundance.

References

Abel P.D. (1989). Water Pollution Biology. 2nd ed. Ellis Horwood, Chichester, UK.

Badruzzaman A.B.M., Bari M.F., Alam M.S., Hoque M.M., Habib M.E., Saha M. (2007). Effects of thermal effluent discharge on the macroinvertebrate abundance in the Sitalakhya River in Bangaladesh. In: Proceedings of the Scientific Conference; Rivers of the Hindu-Kush Himalaya-Ecology and Environmental Assessment, pp: 113.

Barbour M.T., Gerritsen J., Snyder B.D., Stribling J.B. (1999). Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish, 2nd ed. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Bartsch M.R., Newton T.J., Allran J.W., O'Donnell J.A., Richardson W.B. (2003). Effects of pore-water ammonia on in situ survival and growth of juvenile mussels (*Lampsilis cardium*); in the St. Croix Riverway, Wisconsin, USA. Environmental Toxicology and Chemistry, 22(11): 2561-2568.

Begon M., Townsend C.R., Harper J.L. (2006). Ecology: from individuals to ecosystems. 4th ed. Wiley-Blackwell, USA.

Bode R.W., Novak M.A., Abele L.E. (1996). Quality assurance work plan for biological stream monitoring in New York State. NYS Department of Environmental Conservation, Albany, NY. 89 p.

Bode R.W., Novak M.W., Abele L.E. (1991). Methods for rapid biological assessment of streams. Stream Biomonitoring Unit, Bureau of Monitoring and Assessment, Division of Water, NYS Dept. of Environmental Conservation. 57 p.

Bonada N., Prat N., Resh V.H., Statzner B. (2006). Developments in aquatic insect biomonitoring: a comparative analysis of recent approaches. Annual Review of Entomology, 51: 495-523.

CEA (2001). Proposed Ambient Water quality Standards for Inland Waters in Sri Lanka. Colombo, Sri Lanka: Environment Action Project (Funded by ADB).

Choubisa S.L. (1992). Molluscs as bio-indicators for the trophic stages of lakes and lotic environments. Bulletin of Pure and Applied Science, 11: 35-40.

Clarke A.H. (1979). Gastropods as indicators of trophic lake stages. Nautilus, 94: 138-142.

Dahanayaka D.D.G.L., Wijeyaratne M.J.S. (2006). Diversity of macrobenthic community in the Negombo estuary, Sri Lanka with special reference to environmental conditions. Sri Lanka Journal of Aquatic Science, 11: 43-61.

Dharmasoma U.Y.I.L., Piyadasa R.U. (2014). An Assessment of seasonal variation water quality in the inlets of Diyawannawa Lake, Sri Lanka. In: Proceedings of the SAITM Research Symposium on Engineering Advancements. pp: 110-112.

Feio M.J., Almeida S.F.P., Craveiro S.C., Calado A.J. (2007). Diatoms and macroinvertebrates provide consistent and complementary information on environmental quality. Fundamental and Applied Limnology, 169: 247-258.

Fernando C.H., Weerawardhena S.R. (2002). A guide to the fresh water fauna of Ceylon (Sri Lanka). A reprint of A.S. Mendis and C.H. Fernando (1962) with a forward, a check list of Amphibians of Sri Lanka and selected references on freshwater fauna. 2nd ed. Department of Fisheries, Sri Lanka. 173 p.

Gamlath G.A.R.K., Wijeyaratne M.J.S. (1997). Indicator organism of environmental conditions in a lotic water body in Sri Lanka. Sri Lanka Journal of Aquatic Science, 2: 121-129.

Hartmut F., Gerstmann S. (2007). Declining populations of freshwater pearl mussels (*Margaritifera margaritifera*) are burdened with heavy metals and DDT/DDE. Ambio, 36(7): 571-574.

Hellawell J.M. (1986). Biological indicators of freshwater pollution and environmental management. 1st ed. Elsevier, London. 518 p.

Hilsenhoff W.L. (1988). Using a biotic index to evaluate water quality in streams. Tech. Bull. No 132 Wisconsin Department of Natural Resources.

Idroos F.S., Manage P.M. (2012). Aquatic life health quality assessment of the Bolgoda Canal and Waga Stream with respect to selected physico-chemical parameters and bioindicators.

Journal of Tropical Forestry and Environment, 2(2): 13-26.

Jacobson P.J., Farris J.L., Cherry D.S., Neves R.J. (1993). Juvenile Frshwater mussel (Bivalvia, Uninoidae) responses to acute toxicity testing with copper. Environmental Toxicology and Chemistry, 12: 879-883.

Kazi T.G., Arain M.B., Jamali, M.K., Jalbani N., Afridi H.I., Sarfraz R.A., Baig J.A., Shah A.Q. (2009). Assessment of water quality of polluted lake using multivariate statistical techniques: A case study. Ecotoxicology and Environmental Safety, 72(2): 301-309.

Kolodziejczyk A. (1984). Occurrence of Gastropoda in the lake littoral and their role in the production and transformation of Detritus 1. Snails in the Littoral of Mikolajskie Lake- General Characteristics of Occurrence. Polish Journal of Ecology, 32(3): 441-468.

Mereta S.T., Boets, P., De Meester L., Goethals P.L.M. (2013). Development of a multimetric index based on benthic macroinvertebrates for the assessment of natural wetlands in Southwest Ethiopia. Ecological Indicators, 29: 510-521.

Moloukhia H., Sleem S. (2011). Bioaccumulation, fate and toxicity of two heavy metals common in industrial wastes in two aquatic Molluscs. Journal of American Science, 7(8): 459-464.

Páez-osuna P., Frias-espericueta M.G., Osunalópez J.I. (1995). Trace metal concentrations in relation to season and gonadal maturation in the oyster *Crassostrea iridescens*. Marine Environmental Research, 40(1): 19-31.

Plafkin J.L., Barbour M.T., Porter K.D., Gross S.K., Hughes R.M. (1989). Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. EPA.

Riget F., Johansen P.., Asmund G. (1997). Uptake and release of lead and zinc by blue mussels. Experience from transplantation experiments in Greenland. Marine Pollution Bulletin, 34(10): 805-815.

Savage A.A., Gazey G.M. (1987). Relationships of physical and chemical conditions to species diversity and density of gastropods in English lakes. Biological conservation, 42(2): 95-113.

Shuhaimi-Othman M., Nur-Amalina R., Nadzifah Y. (2012). Toxicity of metals to a freshwater snail, *Melanoides tuberculata*. The Scientific World Journal, 1-10.

Triest L., Kaur P., Heylen S., De Pauw N. (2001). Comparative monitoring of diatoms, macroinvertebrates and macrophytes in the Woluwe River (Brussels, Belgium). Aquatic Ecology, 35(2): 183-194.

Turkmen M., Turkmen A., Akyurt I., Tepe Y. (2005). Limpet, *Patella caerulea Linnaeus*, 1758 and barnacle, *Balanus* sp., as biomonitors of trace metal availabilities in Iskenderun Bay, northern east Mediterranean sea. Bulletin of Environmental Contamination and Toxicology, 74(2): 301-307.

Yuzereroglu T.A., Gok G., Cogun H.Y., Firat O., Aslanyavrusu S., Maruldali O., Kargin F. (2010). Heavy metals in *Patella caerulea* (mollusca, gastropoda) in polluted and non-polluted areas from the Iskenderun Gulf (Mediterranean Turkey). Environmental Monitoring and Assessment, 167: 257-264.